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Water Quality Conditions and Restoration of Submerged Aquatic Vegetation (SAV) in the Tidal Freshwater James River 2009

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EXECUTIVE SUMMARY

In 2009, wild celery (*Vallisneria americana*) and water stargrass (*Heteranthera dubia*) shoots were transplanted into shallow water sites in the Hopewell region of the tidal James River and sampled for survivorship and growth throughout the SAV growing season. Water quality sampling was conducted at bi-weekly to monthly intervals throughout the year for water column nutrients, chlorophyll a, suspended solids, water transparency and other chemical and physical constituents important for SAV growth. Objectives of this restoration and water quality study were to: 1) expand the SAV transplanted plots within the study areas previously transplanted; 2) conduct water quality sampling to determine the state of water quality for 2009 in the tidal freshwater James relative to current water quality standards and SAV habitat requirements; 3) evaluate SAV transplant performance and compare to water quality conditions; 4) monitor SAV re-growth in the upper tidal James River.

SAV transplant growth and survival again occurred at all James River field sites at depths of approximately 0.4-0.5 m below low water. Water stargrass and wild celery stocks originally collected from non-tidal areas of the James and planted into grow out nursery ponds at VIMS, were transplanted into the enclosed tidal restoration sites in 2008. SAV growth throughout the tidal freshwater James continued to expand in 2009 reaching over 350 acres. All three species grew to form beds with canopies of 60-90 cm and maximum bottom covers of 60 to 100%. Powell's Creek plantings continued to expand with coontail (*Ceratophyllum demersum*) plantings mixed with recruited hydrilla reaching over 68 acres in 2008.

Water quality monitoring in the tidal James River in 2009 indicated that turbidity levels were again suitable for SAV growth to depths of 0.5 m in most areas, but did not meet levels suitable for SAV growth to 1m depths. Seasonal light levels were at or near water clarity criteria for growth to 0.5m depths at most transplant sites. Turbidity levels were lowest in the upper section of the JMSTF2 near Richmond. When integrated along each of the freshwater segments (JMSTF1 and JMSTF2) using continuous underway spatial sampling, turbidity levels for growth to 0.5m were met for all eight SAV growing season cruises. Summertime levels of chlorophyll were generally lower than 2007. When integrated across the entire segments, average concentrations were found to be well above spring and summer limits of 15-23 $\mu g\ l^{-1}$ and 10-15 $\mu g\ l^{-1}$ for JMSTF1 and JMSTF2 respectively. Similarly, average seasonal concentrations at the transplant sites were above SAV growing season goals of 15 $\mu g\ l^{-1}$ and ranged from 30 to 72 $\mu g\ l^{-}$ during the spring and 72-82 $\mu g\ l^{-}$ during the summer. No noxious blooms or other symptoms of excess algae were observed, however. Nutrient levels generally were comparable with earlier years' monitoring results, although increases in analytical detection limits precluded trend analysis. Total kjeldahl nitrogen, dissolved ammonium and dissolved inorganic phosphorus concentrations were at or below detection for most of the year. Dissolved nitrate plus nitrite also were below detection during the summer, while total phosphorus showed higher concentrations than in previous years.

Overall, the success of the SAV restoration and growth in the tidal freshwater James River is encouraging Most water quality parameters remain consistent from earlier years, but continued high levels of chlorophyll are still prevalent during the summer.

1.0 Background and Objectives

In 1999, the Hopewell Regional Wastewater Treatment Facility (HRWTF) along with the Virginia Institute of Marine Science (VIMS) initiated a long-term study to transplant and re-introduce several species of underwater grasses to the tidal freshwater James River (Figure 1-1). Additionally, water quality was monitored to quantify the conditions associated with the SAV growth and survival. Until this work began in 1999 no transplants of SAV had been formally attempted in the tidal freshwater region of the James River. Since that time SAV acreage in tributaries in this region of tidal freshwater James (JMSTF1) has increased to approximately 300 ac. in 2008 and 2009 (Figure 1-2). The majority of this SAV has been found growing in various tidal tributary creeks in this region where it consists of *Ceratophyllum demersum* (coontail), *Heteranthera dubia* (water stargrass), *Naiad* sp. (naiads), *Elodea canadensis* (common elodea), *Hydrilla verticillata* (hydrilla) and *Vallisneria americana* (wild celery), but little in the main area of the James where much of the historical SAV occurred. Results of our transplant experiments throughout the course of the previous studies have been successful and have demonstrated that a variety of native SAV species can grow and reproduce in shallow water areas in this region of the river under current conditions, if protected from grazing and herbivory. Expansion of SAV transplants outside of protective exclosures in open flats of the James River has been found to be limited, as the plants are repeatedly cropped to about one inch in length and eventually die. The overall results of this long term study have been that if protected from herbivory SAV can be successfully transplanted into this region of the tidal James River. In addition, the wild celery has been shown to be successfully transplanted either as seeds or whole, bar-rooted plants. Using either method it will grow rapidly and produce flowering shoots and overwintering buds and other structures during the first year of growth, and will revegetate the subsequent spring. Other species have been shown to grow and survive during the planting year but wild celery demonstrated the best regrowth from year-to-year. If protected from herbivory, areas transplanted with wild celery at ¼ m spacing will reach 100% cover within three years or less.

This project has principally focused on SAV restoration and water quality monitoring at five shoal areas along the main axis of the James River near Hopewell, Va. at sites where historical aerial photography has shown SAV beds had been growing in the 1940s and earlier. The physical exposure and substrate at these sites varies from protected and muddy to exposed and sandy. Survival and growth of the SAV at the study sites has been generally consistent over the 10-year study period. In 2002 there was a severe drought in the region and as freshwater runoff decreased throughout the summer salinities increased up to 5-6 PSU in the region. Due to these high salinities the SAV died out at the transplant sites, however there was some limited recovery in 2003.

Both transplanted and naturally recruited SAV within several of the smaller tidal creeks in the area has also been measured. Many of these SAV beds are now vegetated by hydrilla which has naturally spread into these areas, perhaps using waterfowl as vectors. Other species in these creek areas include coontail, common elodea and naiads. Wild celery has also been identified in a few locations. In 2001, SAV consisting of native wild celery, coontail and elodea stock obtained from the Chickahominy River were transplanted into 10 sites within upper Powell's Creek with the assistance of Mr. Wilson Enochs, a local landowner (Moore et al. 2002). Here, coontail was the most successful of the transplanted species. Over the next few years however, these transplanted areas in the creek became dominated by hydrilla.

In the Potomac River an initial expansion of hydrilla was followed by a resurgence in native species (Rybicki and Landwehr 2007) and decline of hydrilla. Potentially this scenario may occur in the tidal James River. Typically, hydrilla is much more sensitive to higher salinities than many of the other freshwater SAVspecies found in the James River, and periodic increases in salinity during drought years may be limiting its growth and recruitment there. Higher wave and tidal energies also may be limiting species such as hydrilla that have branching canopy types in the exposed areas of the James.

1.1 Statement of Problem

The Commonwealth of Virginia Draft Tributary Strategy, "Goals for Nutrient and Sediment Reduction in the James River", identifies reduced light penetration preventing the growth of SAV as one of the key issues regarding water quality and living resource impacts. The strategy states, "Restoration of grass beds to the upper tidal river will greatly expand existing recreational fishing opportunities for largemouth bass and other tidal fresh sport fish. Once grass beds gain a foothold, they will also begin to improve water quality themselves by stabilizing shorelines, minimizing resuspension of sediments into the water due to wind and waves, and filtering nutrients out of the water." In addition, EPA listed the James River on the 303(d) List as impaired for aquatic life use attainment and its improvement is an integral part of the Commonwealth's 2010 Watershed Implementation Plan. SAV is a vital resource that produces oxygen, provides a nursery, food and protection for a variety of aquatic organisms, reduces the erosion effect of wave energy, absorbs nutrients and other pollutants, traps sediments, and serves as an important indicator of the health of the James River. Therefore, its restoration is closely tied to water quality and water quality improvements.

Analysis of historical aerial photographs and ground survey reports for SAV in the James River revealed that shallow water areas of the James River near the City of Hopewell supported SAV growth until the mid-1940s (Moore et al. 1999). Until 1999, SAV had been found only in scattered patches in a few small tributary creeks in this region of the James River (Moore et al. 1999). Freshwater SAV are a potentially important component of the ecosystem because of their value to fish and waterfowl, and their recovery can be an important catalyst for positive ecosystem change throughout the region as have been in the upper Potomac River. Chesapeake Bay Model evaluations of the continuing improvements to point source discharges in this region and water quality monitoring of the James through this and other studies suggests that water quality in many areas may be suitable for SAV growth. One way to assess these various hypotheses is to use SAV transplants to test the current suitability of the areas for SAV. Using SAV plants directly can provide an integrated measure of habitat suitability that cannot be determined solely by discreet monitoring of physical and chemical habitat conditions. In addition, once established they can provide a local source of propagules to hasten recovery.

1.2 Project Objectives

During 2009 objectives of the SAV restoration and water quality monitoring efforts, funded by HRWTF were to:

1) Conduct fixed station water quality sampling at four shallow water sites (1m depth) in the James River at twice a month intervals from April through October and monthly from November to March.
2) Monitor the SAV transplant sites for SAV growth and survival. Relate the response of the transplants to changing water quality conditions in the shallows during the growing

season and in turn evaluate the cause/effect relationships between water quality and SAV habitat recovery.

3) Evaluate SAV abundance throughout the tidal freshwater James River and its tributaries through review of SAV aerial photography and ground survey information.

2.0 Methods

2.1 Study Sites

Four shallow water sites (Figure 1-1) were used for SAV transplanting and/or water quality monitoring in the Hopewell region of the James River estuary in 2009. One previous site, in the Shirley Cove area, was discontinued in 2007 due to periodic disturbance by ongoing dredge disposal from maintenance of the navigation channel in that area.

Turkey Island	Lat. 37.3826 N	Long. 77.2527 W
Tar Bay	Lat. 37.3075 N	Long. 77.1902 W
Powell's Creek	Lat. 37.2929 N	Long. 77.1622 W
Westover Plantation	Lat. 37.3105 N	Long. 77.1558 W

2.2 SAV Transplanting and Monitoring

Transplanting activities at Westover, Powell's Creek and Tar Bay transplant sites in the James River were undertaken inside protective mesh exclosures in June of 2008 using bare-rooted water stargrass, and wild celery. These donor plants were obtained from nursery grown James River stock established in grow out ponds at the campus of VIMS in Gloucester Point, VA (Moore et al. 2007). Transplants were surveyed by a diver at bi-weekly to monthly intervals beginning in July 2009 for percent survival and shoot length of planting units. Observations were also made on the relative condition of the transplants, including any evidence of herbivory.

2.3 Water Quality Monitoring

VIMS personnel conducted water quality sampling at bi-weekly to monthly intervals at each of the present and former James River restoration sites from January to December 2009. This resulted in a continuous record of water quality conditions from previous monitoring starting in 1999. Water quality measurements included: air and water temperatures, secchi depth, light attenuation profiles (K_d), pH, conductivity, organic and inorganic nitrogen and phosphorus, chlorophyll, suspended solids, dissolved oxygen, total organic carbon and nitrogen. Samples were obtained at the shallow water transplant sites in water depths of approximately one meter. Water samples were collected at a depth of one-half meter below the surface. Water samples were placed in clean, pre-labeled containers provided by HRWTF personnel and stored on ice in the dark until the end of each sampling cruise. At that time the samples were returned to HRWTF personnel for subsequent laboratory analyses according to Standard Methods (APHA, AWWA, & Water Environment Federation 1995). Water quality analyses resulting at concentrations at the detection limits are presented as one-half the analytical detection limit.

3.0 RESULTS

3.1 SAV Transplant Survival

Percent cover for 2009 are presented in Figure 3-1. At all sites the wild celery rapidly expanded in June and by early July had reached nearly 100% cover at the Powell's Creek site, over 90% cover at the Westover site and nearly 80% cover at Tar Bay. This growth demonstrated that nearly full SAV cover can be reached by wild celery in only two seasons. In contrast, plots with water stargrass had less than 10% cover at Westover and less than 30% at

Powell's Creek by early summer. The water stargrass transplants at Tar Bay did not survive from 2008. The wild celery maintained consistent cover throughout the 2009 season at all sites until September when it was found to have declined markedly. Water stargrass showed little increase in cover at Powell's Creek and only modest growth at Westover, reaching 20-30% cover at both sites. Transplants at the Tar Bay site consisted of largely wild celery, however a few natural recruits of horned pondweed (*Zannichellia palustris*) were found growing throughout the exclosure during July and August. Typically, horned pondweed grows well during the spring and early summer in a variety of low salinity areas throughout the Chesapeake Bay. It reproduces primarily from seed and after seeding in the early summer dies out completely.

Shoot length measurements showed a general decline in lengths throughout the year at both the Powell's Creek and Westover sites (Figure 3-1). This was unusual, as in past years the SAV typically maintained longer shoots throughout the growing season until the fall. No extensive herbivory was observed. At Tar Bay the average wild celery shoot length was maintained at about 50cm. The much longer plants of water stargrass observed at Westover were due, in large part, to the existence of few long stargrass plants, in contrast to the more extensive cover of wild celery that included a number of newer and shorter shoots. The few long plants of stargrass resulted in a skewed mean length distribution for that site. The lack of spread of stargrass at both Powell's Creek and Westover may have been related to the dense cover of wild celery which may have inhibited its lateral spread.

Aerial photography taken in the summer of 2009 (Figure 3-2) revealed SAV beds within Powell's Creek very comparable to those found in 2008 (Moore et al. 2009) with approximately 70 acres present in the creek. SAV in the creek system consisted principally of hydrilla, coontail and common elodea although hydrilla has become the dominant species (Orth et al. 2009). The lack of change since 2008 suggests most of the shallow water potential SAV habitat is currently vegetated with SAV in the creek system. The resurgence of SAV in the creek system first began in several of the smaller branches, several of which were planted with SAV in 2001 and 2002. It was not until 2006 that the SAV spread throughout the system. While water quality conditions were not markedly different during this period, the resurgence did follow several years of generally low salinity (conductivity) in the region.

3.2 Water Quality Monitoring

Air and water temperatures (Figures 3-3 and 3-4) demonstrated similar annual patterns over the 1999-2009 sampling period at all the stations with daytime minimum air and water temperatures ranging from approximately 5 °C to maximums of 35-40 °C for air and 30-33 °C for the water. Water temperatures appeared to have increased a bit more rapidly in the spring of 2009 compared to 2008, but this early warming pattern has been observed in other years. The rapid growth in SAV at the sites may be related to this more rapid warm up in water temperatures early in the year. As with most years the seasonal decline in the vegetation is observed as water temperatures decrease below 20 °C.

Conductivity (Figure 3-5) showed slight increases in the late summer and fall of 2009 which were comparable to similar periods in 2007 and 2008. This is in contrast to the markedly higher conductivities observed in 2001 and 2002 when the transplanted SAV nearly all declined due to salinity stress at the end of the summer. Westover always has had the highest peak salinities and the poorer growth of species other than wild celery and may have been due to the slightly higher salinities at this site.

Daytime dissolved oxygen (D.O.) concentrations (Figure 3-6) at the transplant sites continued to be high in 2009 and were above 8 mg/l even during the summer with no consistent differences observed among the stations. Water column pH levels were also high (Figure 3-7) and paralleled D.O. levels. High daytime D.O. can be related to high primary production for phytoplankton, however no long term relationship between D.O. and measured phytoplankton concentrations appears evident over time. Markedly lower pH was observed in late summer and fall of 2002. This appeared associated with the low flows and higher conductivities observed during that period. Higher salinities tend to buffer pH conditions. The apparent lack of a similar drop in D.O. further suggests that this was related to salinity and not a change is system metabolism.

Suspended particle concentrations (TSS) were consistent among stations and showed few peaks compared to earlier years (Figure 3-8) with no long term or seasonal trends evident. Levels typically ranged from 10-30 mg/l. Table 1 presents median TSS concentrations and other SAV habitat criteria for the SAV growing season (April 1- October 31) at each transplant site. Sites which met the individual water quality criteria are shaded in grey. Suspended sediment concentrations in 2009 during the SAV growing season exceeded the habitat criteria of <15mg/l for SAV growth to 1m at all sites suggesting that under existing conditions re-colonization of SAV to 1m depth will be difficult. These high levels of suspended sediments are not unusual for this region of the James River, which is within the turbidity maximum zone of the river. SAV growing season mean levels were lower in 2009 than in previous years and in fact were the lowest recorded since 1999. This potentially downward trend is encouraging.

Water transparencies measured as secchi depth (Figure 3-9) demonstrated little year-to-year variability over the past several years, although conditions during 2009 were less variable than most years. Light attenuation measurements (Figure 3-10) paralleled that of TSS and were lower in 2009 than in all previous years (Table 1). Turbidity in this region of the river is largely affected by suspended sediment and the patterns of light availability parallel that of TSS. SAV growing season secchi depths for SAV growth to 0.5m met the goal at all the sites in 2009 (Table 1). Growing season median light attenuation (K_d), another measure of light availability, was also met for a SAV restoration depth of 0.5m at all of sites and this is reflected in the success of the SAV transplants.

Chlorophyll levels in 2009 demonstrated continuing high levels throughout the SAV growing season with concentrations exceeding 100 ug/l (Figure 3-11). Summertime levels were comparable to those in 2007 and 2008. Median SAV growing season chlorophyll concentrations for each of the monitoring sites (Table 1) show that chlorophyll levels continue to be well above the habitat criteria established for SAV growth to depths of 1m. No appreciable effect of high phytoplankton levels on SAV growth has been apparent, however, as the SAV transplants continue to be successful and grow. In part, this lack of observable effect may be due to the shallowness (~0.5m) of the SAV transplants and the overwhelming effects of suspended sediments on light attenuation even at these relatively high levels of chlorophyll.

Table 2 presents the mean chlorophyll concentrations for the March-May (spring) and July-September (summer) periods for the SAV transplant stations within each of the two James River Tidal Freshwater segments (JMSTF1 and JMSTF2) for the years 1999-2009. Numeric chlorophyll standards for the spring and summer seasons were again exceeded at all of the transplant sites for the spring and summer.

Total organic carbon (TOC) concentrations were relatively consistent with lower levels from 2007-2009 compared to 2001-2006. (Figure 3-12). Total kjeldahl nitrogen (TKN) levels were (Figure 3-13) seasonally highest during the summer. There was an increase in the analytical detection limit for TKN in 2008 from 0.6 mg l^{-1} to 1.0 mg l^{-1} which affects any long affected by suspended sediment and the patterns of light availability parallel that of TSS. SAV growing season secchi depths for SAV growth to 0.5m met the goal at all the sites in 2009 (Table 1). Growing season median light attenuation (K_d), another measure of light availability, was also met for a SAV restoration depth of 0.5m at all of sites and this is reflected in the success of the SAV transplants.

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Nitrate + nitrite levels (Figure 3-15) have shown continual seasonal periodicity with highest levels in the winter and early spring as runoff from the watershed is highest. Low levels are found during the summer. No apparent long-term change is evident. Concentrations of ammonium were again at or below detection throughout much of 2009 although the detection limit increased to 0.2 mg l^{-1} in 2008 (Figure 3-16). Concentrations were highest during 2002 when river flow was lowest and water residence time highest. Periodically high levels of ammonium have been observed though out the time course of the study. These may be related to pulsed inputs of ammonium from point sources or the upwelling of bottom water, high in ammonium, from the channel to the shallow littoral zones monitored here.

Dissolved inorganic phosphorus (DIP) concentrations (Figure 3-17) did not meet the SAV growing season habitat criteria threshold of 0.02 mg l^{-1} in 2009 due to a continuing high detection limit up to 0.06 mg l^{-1} for much of 2009 (Table 1). A change back in the detection limit by September of 2009 suggests that DIP was likely similar in concentration in 2009 to previous years.

4.0 SUMMARY AND CONCLUSIONS

Over the past 10 years of this SAV study the results have consistently showed that a variety of SAV species can be transplanted and will grow in the shallow (<0.5m MLW) flats in the main stem region of the tidal James River near Hopewell if protected by exclosure fencing. Of these species wild celery (*V. americana*) appears to be the best species for transplanting and restoration. It will grow from both seeds collected in the fall which are planted in the spring, and will flower and re-grow in subsequent years from overwintering buds. It grows well in both muddy and sandy bottom types and in protected and exposed areas. Anecdotal observations by local landowners suggest that it was the dominant species here when last observed in the 1940s. Wild celery has strap-like leaves and extensive roots and underground stolons to hold it in place during storm events. Hurricane Isabel created extensive shoreline damage and erosion during September 2003, yet the SAV beds vegetated with wild celery were little affected. Although this region of the tidal James River is near the river's natural turbidity maximum zone and is very turbid, growth of the SAV transplants here typically grow up to one meter in length. This means that at water depths of 0.25m MLW during periods of tidal low water, 0.5 to 0.75m lengths of the leaves are floating near the water surface, potentially increasing their capacity to harvest light. These long shoot lengths work against species such as sago pondweed which have a branching shoot structure and limited root material, so that periodic storms can much more easily uproot them from the bottom.

Limited growth outside of these areas has, however, not been observed and therefore recruitment beyond these small transplanted founder beds remains a major bottleneck to native SAV re-growth in the James. While not specifically studied here, our observations and discussions with other scientists in the region suggest that the cropping of SAV plants outside of the exclosures is likely caused by turtles, blue crabs or waterfowl. Occasionally, disruptions to or rips in the plastic mesh exclosures have occurred, and when this happens plants within the exclosures are sometimes cropped. This suggests that the cropping is due to turtles or crabs that come in under the bottom skirt of the mesh near the sediment surface. Traps that have been placed in the exclosures to collect any herbivores have only yielded the blue crab. Fish may be a suspect in the cropping, however, no species that commonly eat or forage SAV are likely to occur here (G. Garmin personal comm.), and it is individual shoots that are cut with little disturbance of the bottom as might be expected by carp or other bottom feeders.

Water quality monitoring in the tidal James River indicates continued adequate water quality for SAV growth in very shallow areas. Turbidity levels were usually suitable for SAV growth to depths of 0.5m. Any increases in water clarity would, however, be expected to increase the depth to which the SAV could grow and spread. Summer phytoplankton concentrations have been increasing since 2005; however these high levels have not precluded SAV transplant growth and survival. Water clarity, in contrast, measured as secchi depth has changed little during the 10-year study period. This is due in large part to the fact that most of the light attenuation here is caused by the high levels of suspended sediments, not phytoplankton. Monitoring of epiphyte loadings on the SAV leaves, which can increase due to high nutrient or suspended sediment levels has shown that there is little increase throughout the season and qualitative observations suggest that increased levels have not occurred over the years. While water quality conditions have not been shown to exclude SAV growth in this region, improvements to water quality, especially water clarity, would likely allow more extensive and rapid growth of the SAV. In part, the herbivory bottleneck that appears to be limiting SAV expansion in the main stem of the James River near Hopewell may be reduced if water clarity were improved. Growth and spreading of these founder colonies appear insufficient to outpace herbivory. Given increased SAV growth potential this may change.

SAV is, however, spreading throughout the many tributary creeks of the James where the habitat is more physically protected, permitting extensive growth by hydrilla and other species that are apical growers, compared to basal growers such as wild celery. Their lack of recruitment into littoral areas along the exposed, open James River may be related to both the physical constraints and well as biological bottlenecks here. Detailed analysis of aerial photographs of Powell's Creek taken since 2000 show the progression of hydrilla down the creek system; having originated at the heads of several small tributaries. It is very likely that hydrilla propagules are therefore spreading throughout the main stem of the James River. This suggests a recruitment bottle neck that may be physical or biological. If hydrilla does spread into the main stem of the James our experience from the Potomac River suggests that native SAV species may likely increase with it, or resurge after a few years of time. The transplantation of unprotected founder restoration may be more successful at that time. Drought years may also reduce the abundance of hydrilla, while increasing the competitive ability of more salt tolerant species such as wild celery to expand and get a foot hold in this region. Given the water quality conditions measured here, it is very likely that they will be able to grow and persist in the shallow flats found throughout this Hopewell region of the James.

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APPENDIX A

TABLES

Table 1. SAV Growing Season (April – October) median water quality. Shaded cell indicates SAV criteria met for SAV growth to 0.5 m. (-) No data. (*) At or below detection limit.

Water Quality Parameter	SAV Habitat Criteria	Turkey Island										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Light Atten.(Kd; m^{-1})	< 3.6	-	-	-	3.87	3.35	3.66	3.58	3.4	3.39	3.89	3.11
Secchi Depth (m)	> 0.40	0.3	0.45	0.39	0.4	0.4	0.3	0.35	0.4	0.4	0.35	0.4
TSS (mg/l)	<15	33.5	26	31.5	30	26	35	32	27.5	31	33	23.1
Chl a (ug/l)	<15	11.1	30.8	30.4	44.8	6.6	9.2	12.5	39.1	76.5	41.7	72.6
DIP (mg/l)	<0.02	0.01*	0.02	0.02	0.02	0.03	0.03	0.02	0.01*	0.01*	0.05*	0.04*

Water Quality Parameter	SAV Habitat Criteria	Shirley Cove										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Light Atten.(Kd; m^{-1})	≤ 3.6	-	-	-	2.8	2.61	2.87	3.12	2.77	-	-	-
Secchi Depth (m)	≥ 0.40	0.4	0.55	0.4	0.4	0.5	0.45	0.45	0.5	-	-	-
TSS (mg/l)	≤15	21	19	22	24	16	21	24	21	-	-	-
Chl a (ug/l)	≤15	13.7	27.5	37	56	8.8	5.65	9.3	32.9	-	-	-
DIP (mg/l)	≤0.02	0.01	0.01	0.01	0.02	0.03	0.03	0.01	0.01	-	-	-

Water Quality Parameter	SAV Habitat Criteria	Tar Bay										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Light Atten.(Kd; m^{-1})	≤ 3.6	-	-	-	3.94	3.72	3.54	3.65	3.33	3.47	3.38	3.00
Secchi Depth (m)	≥ 0.40	0.35	0.4	0.35	0.4	0.4	0.35	0.4	0.4	0.4	0.4	0.4
TSS (mg/l)	≤15	31	28	29.5	34.5	24	32	28	34.5	33	25	21.9
Chl a (ug/l)	≤15	12	26.7	39.1	41.9	4.9	5.3	15.3	32.8	93.3	73.4	65.6
DIP (mg/l)	≤0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.01*	0.01*	0.05*	0.04*

Table 1 (continued). SAV Growing Season (April – October) median water quality. Shaded cell indicates SAV criteria met for SAV growth to 0.5 m. (-) No data. (*) At or below detection limit.

Water Quality Parameter	SAV Habitat Criteria	Powell's Creek										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Light Atten.(Kd; m^{-1})	≤ 3.6	-	-	-	3.91	3.48	4.04	4.04	3.79	3.43	3.89	3.44
Secchi Depth (m)	≥ 0.40	0.3	0.5	0.33	0.4	0.4	0.3	0.4	0.3	0.4	0.35	0.4
TSS (mg/l)	≤ 15	37.5	29	36	35.5	31	38	38	43.5	33	28	23.9
Chl a (ug/l)	≤ 15	12.6	43.2	24	42.5	6.4	5.9	13.6	44.5	103	41.7	73.2
DIP (mg/l)	≤ 0.02	0.01*	0.02	0.02	0.02	0.03	0.03	.01*	0.02	0.01*	0.05*	0.04*

Water Quality Parameter	SAV Habitat Criteria	Westover										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Light Atten.(Kd; m^{-1})	≤ 3.6	-	-	-	3.76	2.99	4.01	3.69	3.37	2.95	3.08	2.93
Secchi Depth (m)	≥ 0.40	-	-	0.4	0.4	0.4	0.3	0.35	0.35	0.4	0.4	0.4
TSS (mg/l)	≤ 15	-	-	30	30	26	32	36	33.5	27	20	18.5
Chl a (ug/l)	≤ 15	-	-	32.4	40.85	5.6	7.2	11.2	42	66.4	51.9	63.8
DIP (mg/l)	≤ 0.02	-	-	0.02	0.02	0.03	0.03	.01*	0.01*	0.01*	0.05*	0.04*

Table 2. Mean (March-May and July-September) chlorophyll concentrations at SAV transplant sites for 1999 through 2008. Shaded cell indicates criteria met.

Season by Year	JMSTF2[1]		JMSTF1[1]		
	Turkey Island (μg/l)	Shirley Cove (μg/l)	Tar Bay (μg/l)	Powell's Creek (μg/l)	Westover (μg/l)
Mar-May 1999	4	5.2	2.8	3.8	-
Mar-May 2000	36.8	30.3	28.4	33.3	-
Mar-May 2001	32.6	28.4	23	19.9	22
Mar-May 2002	23.5	24	18.8	20.8	27
Mar-May 2003	10.8	12	8.9	10.5	14.7
Mar-May 2004	6	6.7	5.4	6.7	6.4
Mar-May 2005	4.3	4	5.8	6.5	5.3
Mar-May 2006	19	19.7	18.6	17	18.6
Mar-May 2007	51.6	-	48.4	65	50
Mar-May 2008	44.1	-	30	72	61.3
Mar-May 2009	34.3	-	27	33.9	33.1
Jul-Sep 1999	41.7	42.1	39.1	38.9	-
Jul-Sep 2000	26.9	37.6	29.2	44.2	-
Jul-Sep 2001	26.7	38.9	34.6	26.4	31.8
Jul-Sep 2002	50.5	62.9	49.9	48.4	45
Jul-Sep 2003	16	10.3	15.4	17.1	14.1
Jul-Sep 2004	15.6	14.2	15.3	16.4	14.4
Jul-Sep 2005	27.7	26	26.3	21.3	25.1
Jul-Sep 2006	76.6	54.1	55.3	61.7	58.1
Jul-Sep 2007	88.5	-	105	90.1	71.5
Jul-Sep 2008	72.8	-	82.4	72	61.3
Jul-Sep 2009	105.6	-	99.6	92.6	87.1

[1] JMSTF 1 - Chlorophyll Limits: March 1-May 31 (15 μg/l); July 1-Sept 30 (23 μg/l)
JMSTF 2 - Chlorophyll Limits: March 1-May 31 (10 μg/l); July 1-Sept 30 (15 μg/l)

APPENDIX B

FIGURES

Figure 1-1. SAV Transplant and Water Quality Monitoring Sites

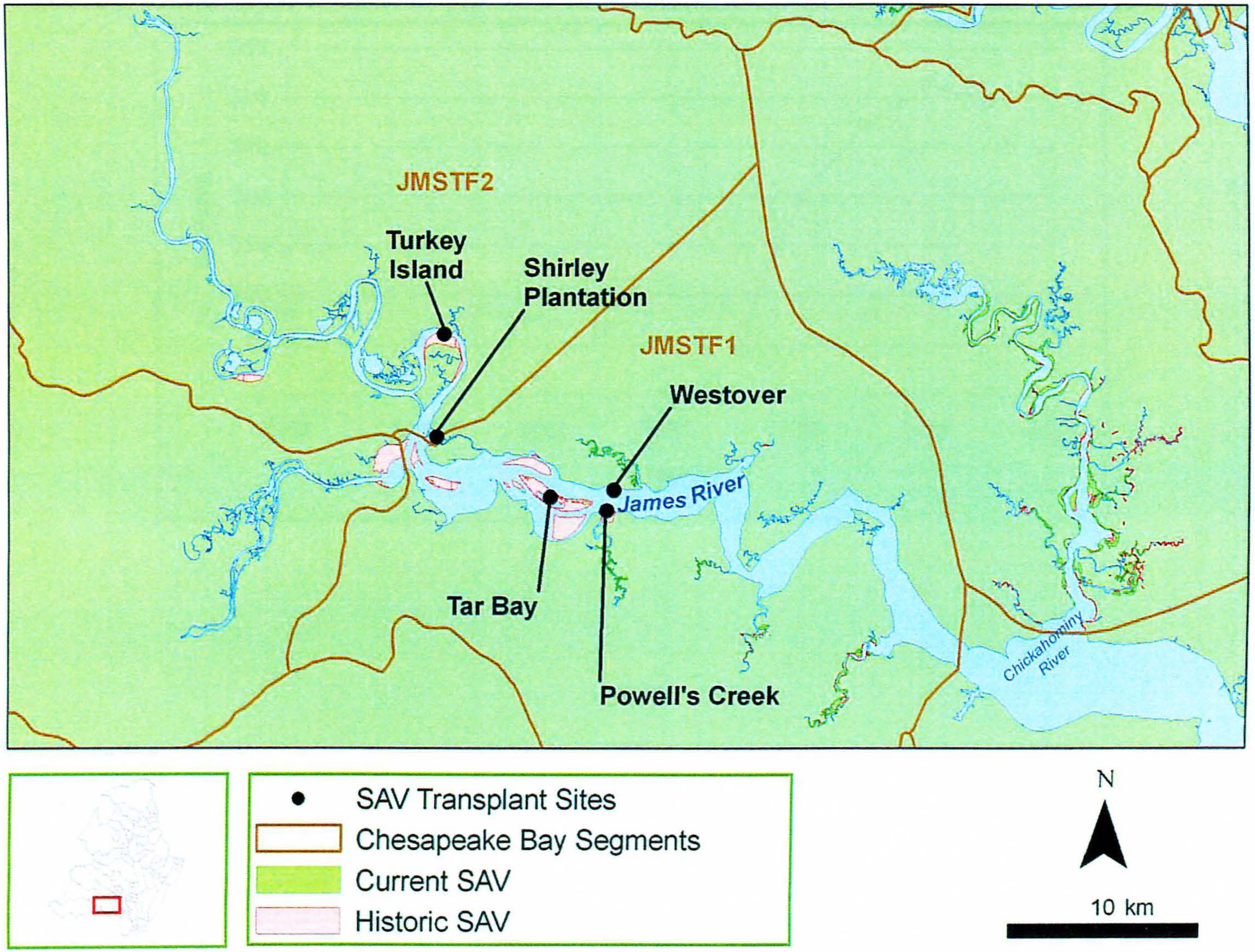


Figure 1-2. SAV Abundance Tidal Freshwater James River

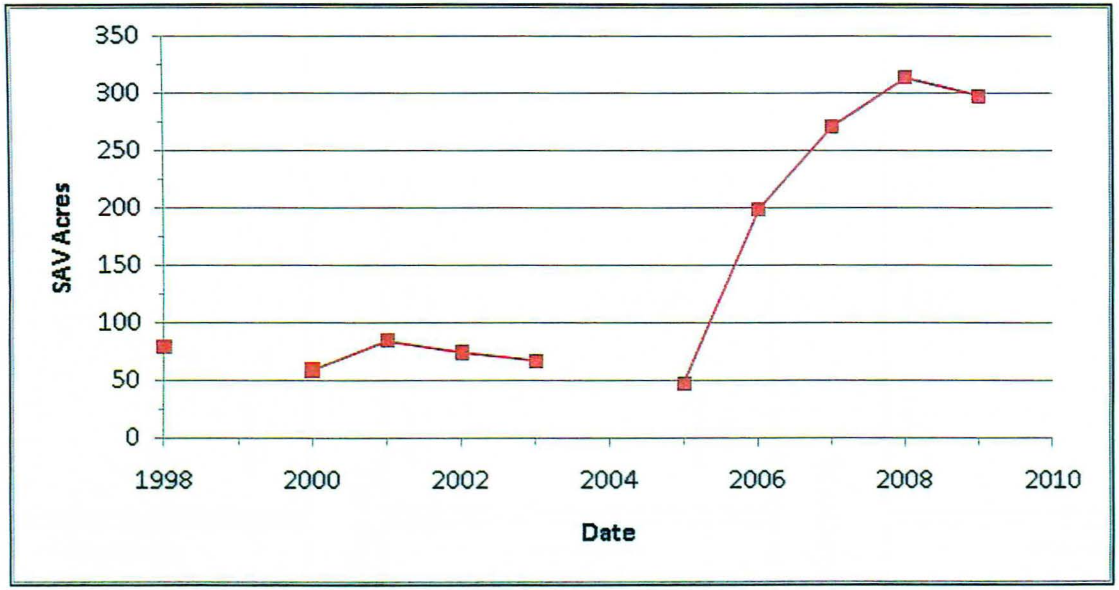
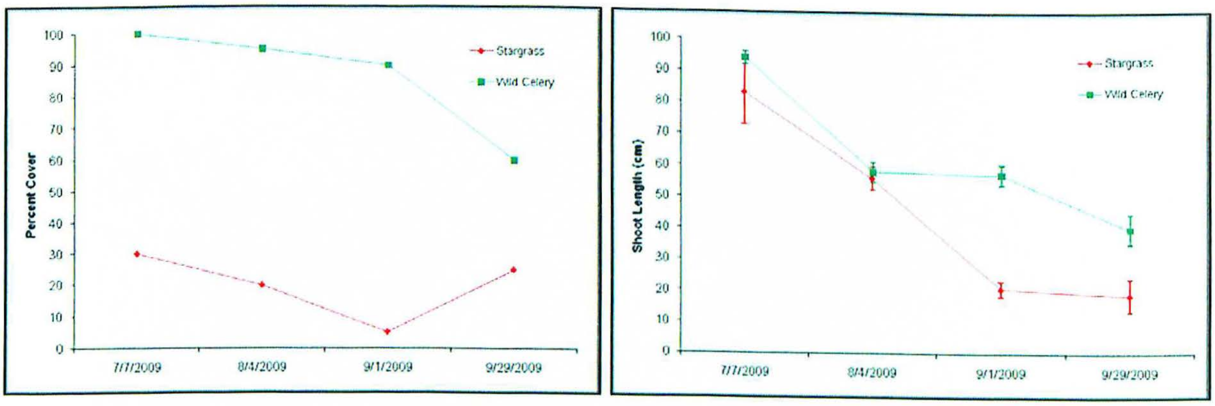
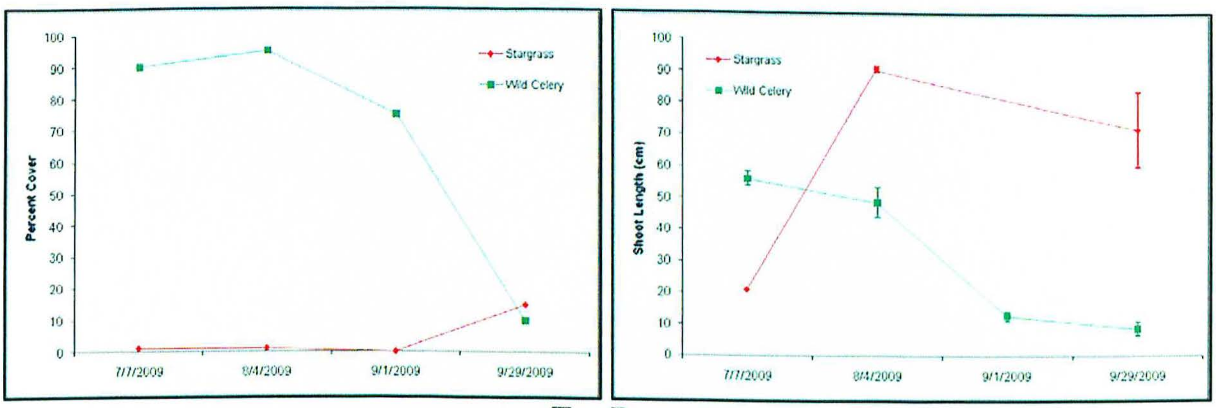


Figure 3-1. 2009 SAV Transplant Growth

Powell's Creek



Westover



Tar Bay

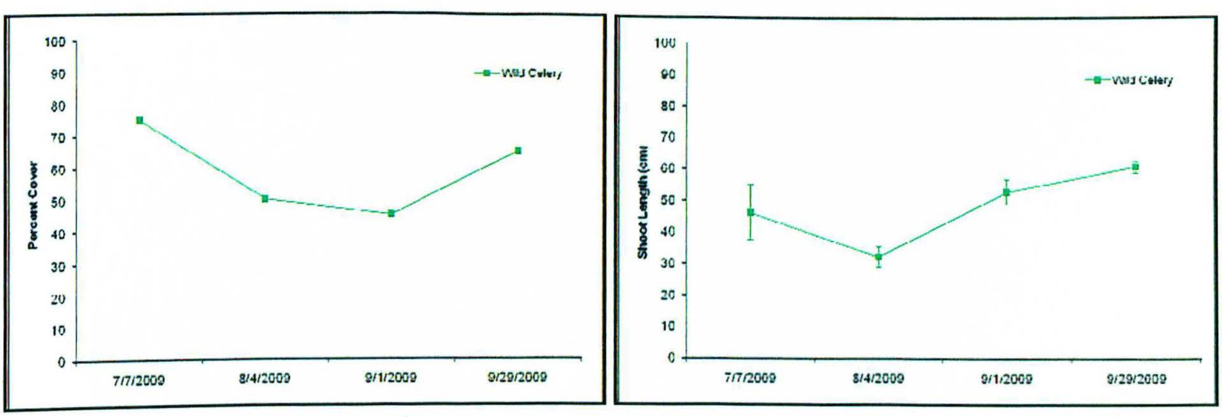


Figure 3-2. 2009 SAV Abundance in Powell's Creek (mapped SAV beds in red)

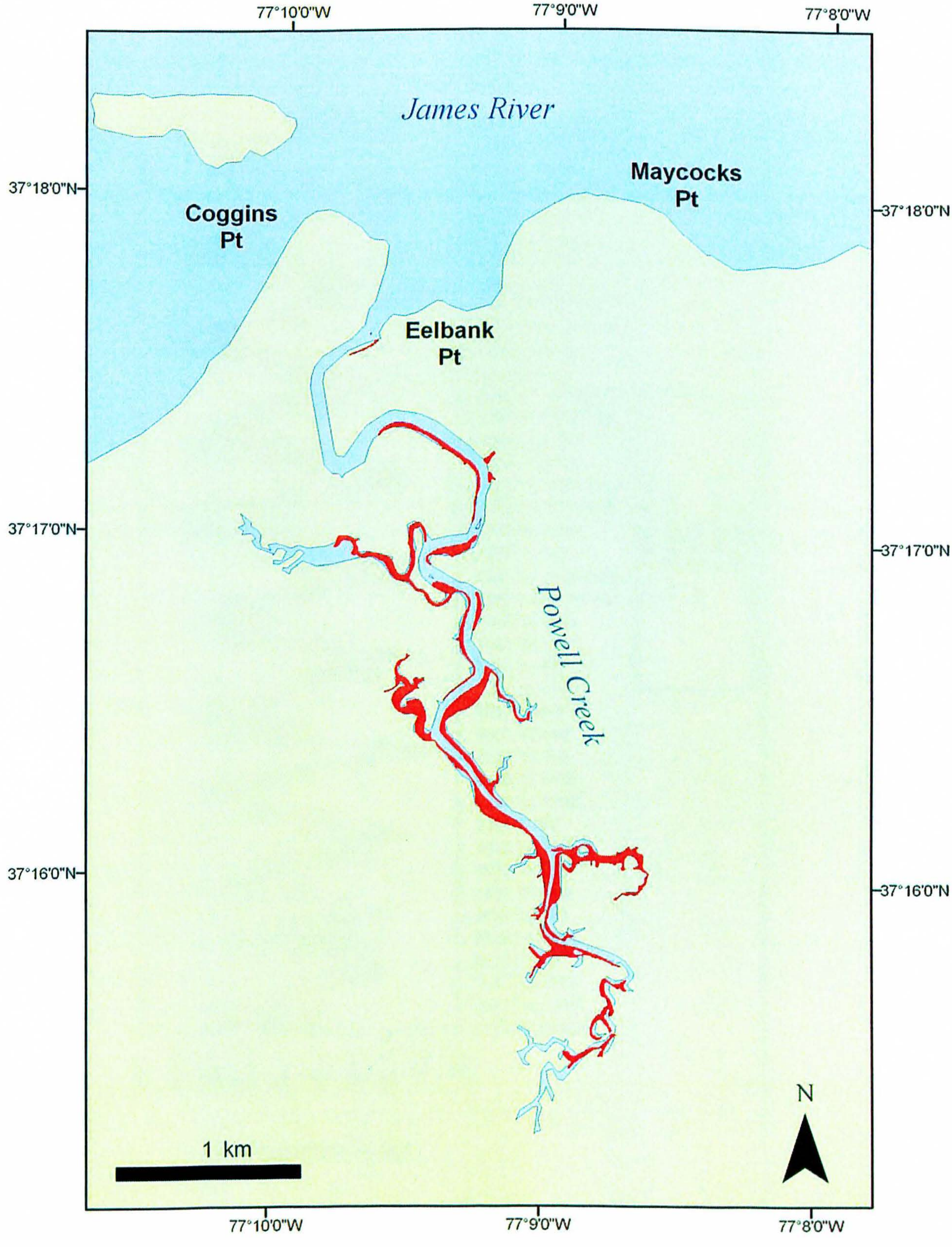


Figure 3-3 Air Temperature

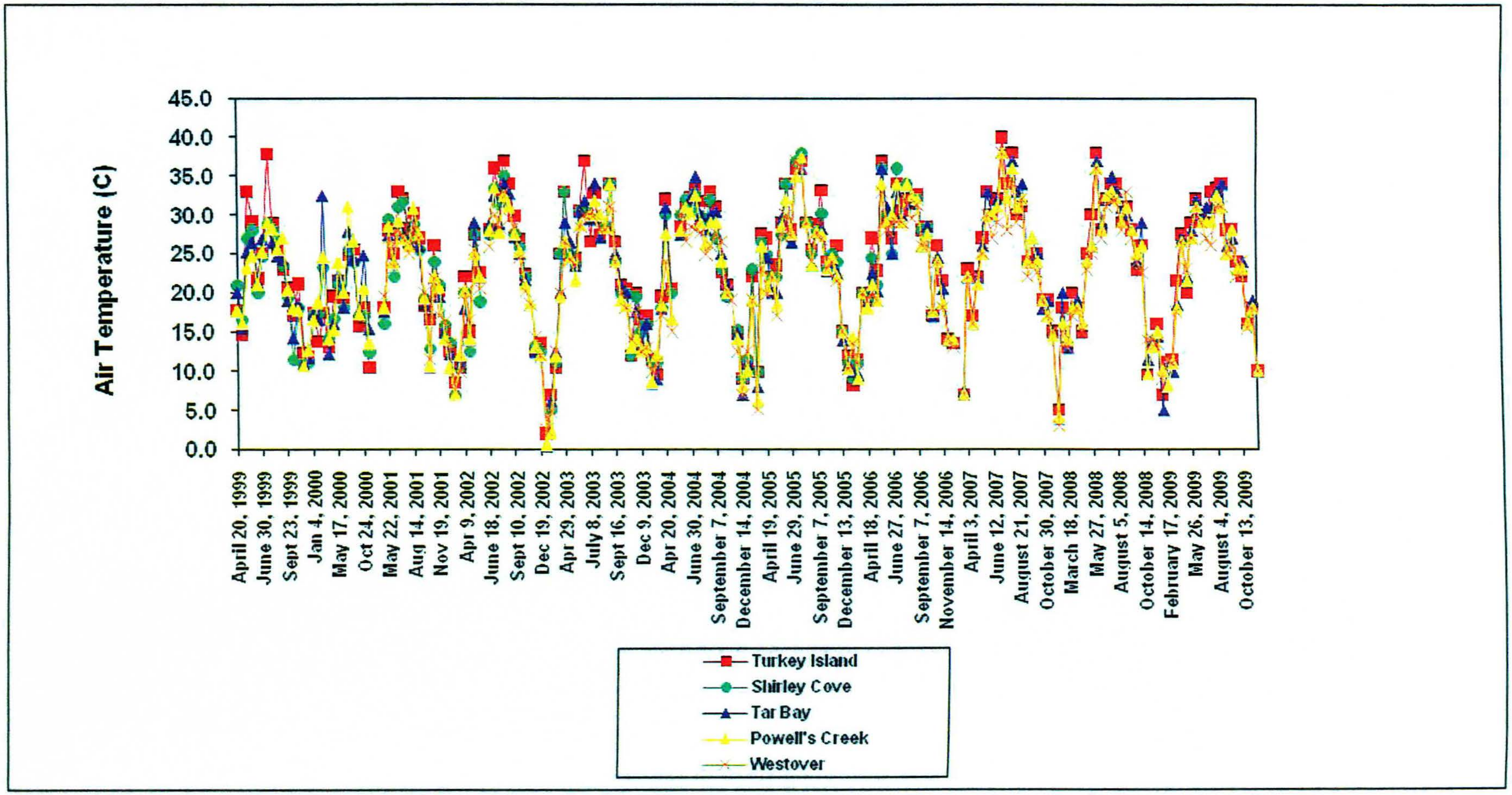


Figure 3-4 Water Temperature

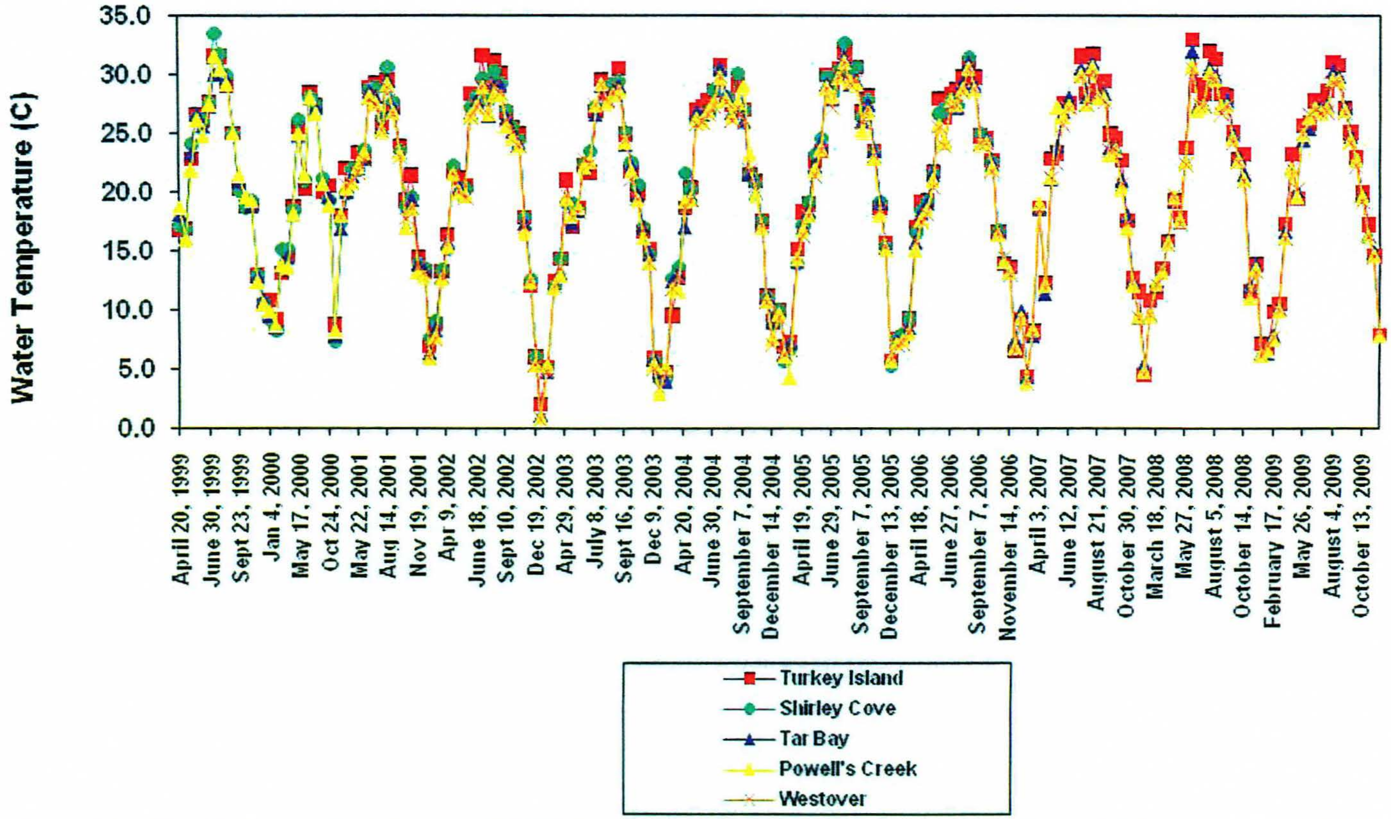


Figure 3-5 Conductivity

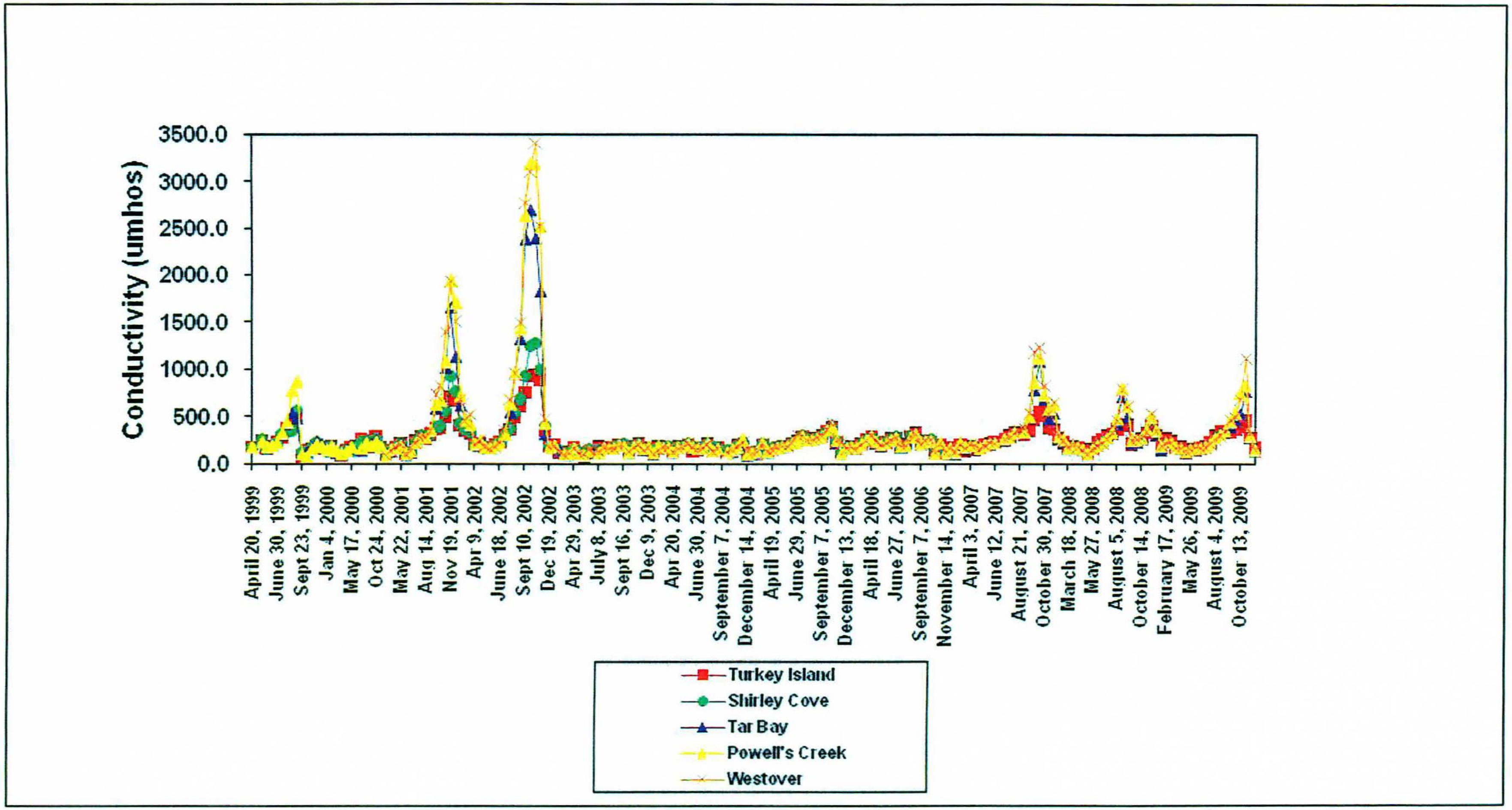


Figure 3-6. Water Column Dissolved Oxygen

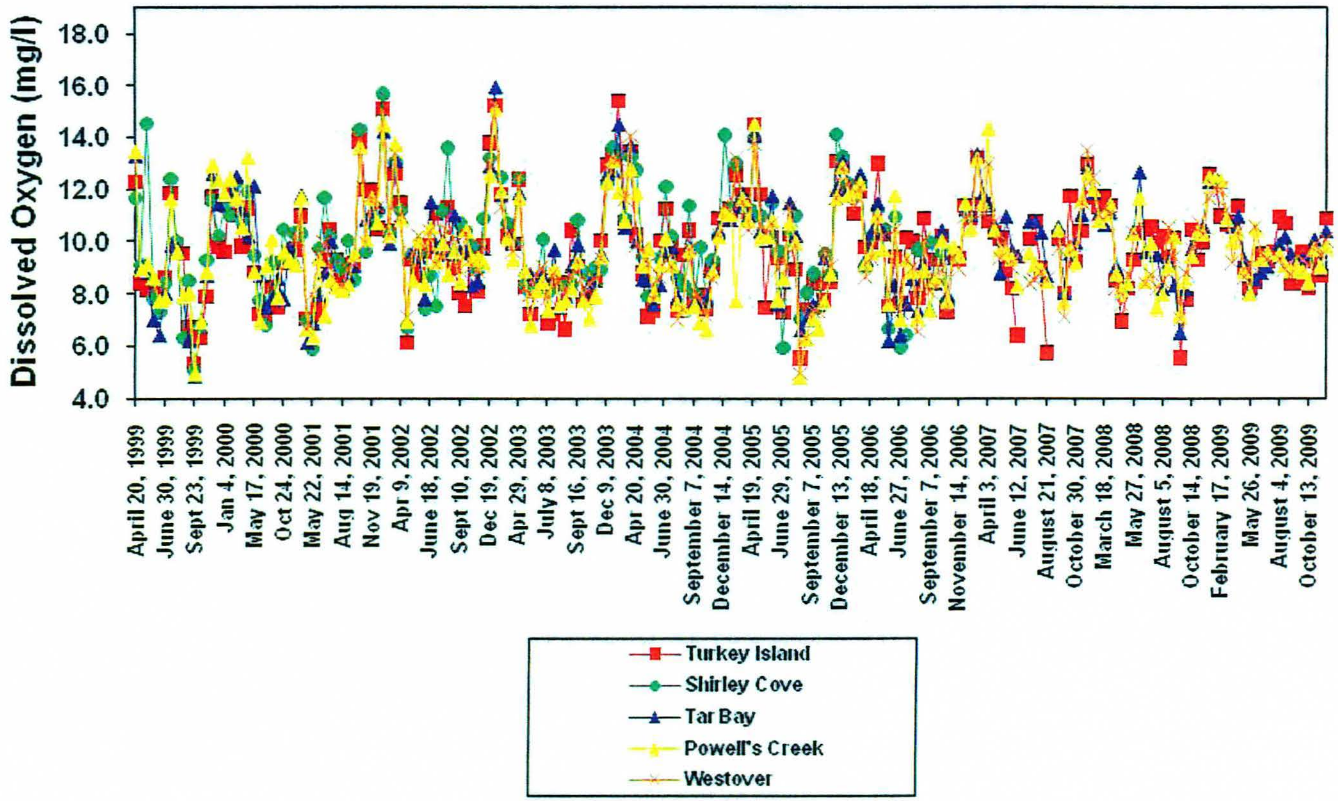


Figure 3-7. Water Column pH

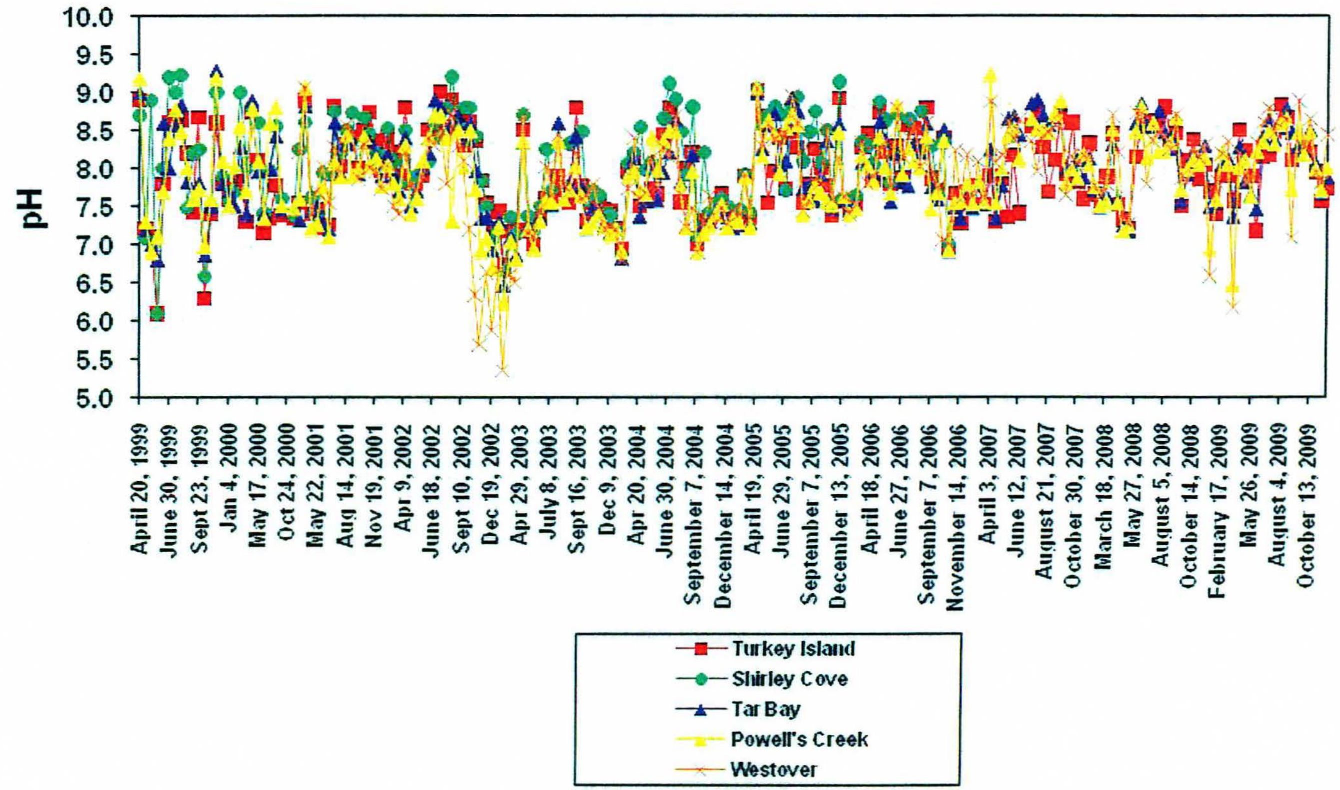


Figure 3-8. Total Suspended Solids

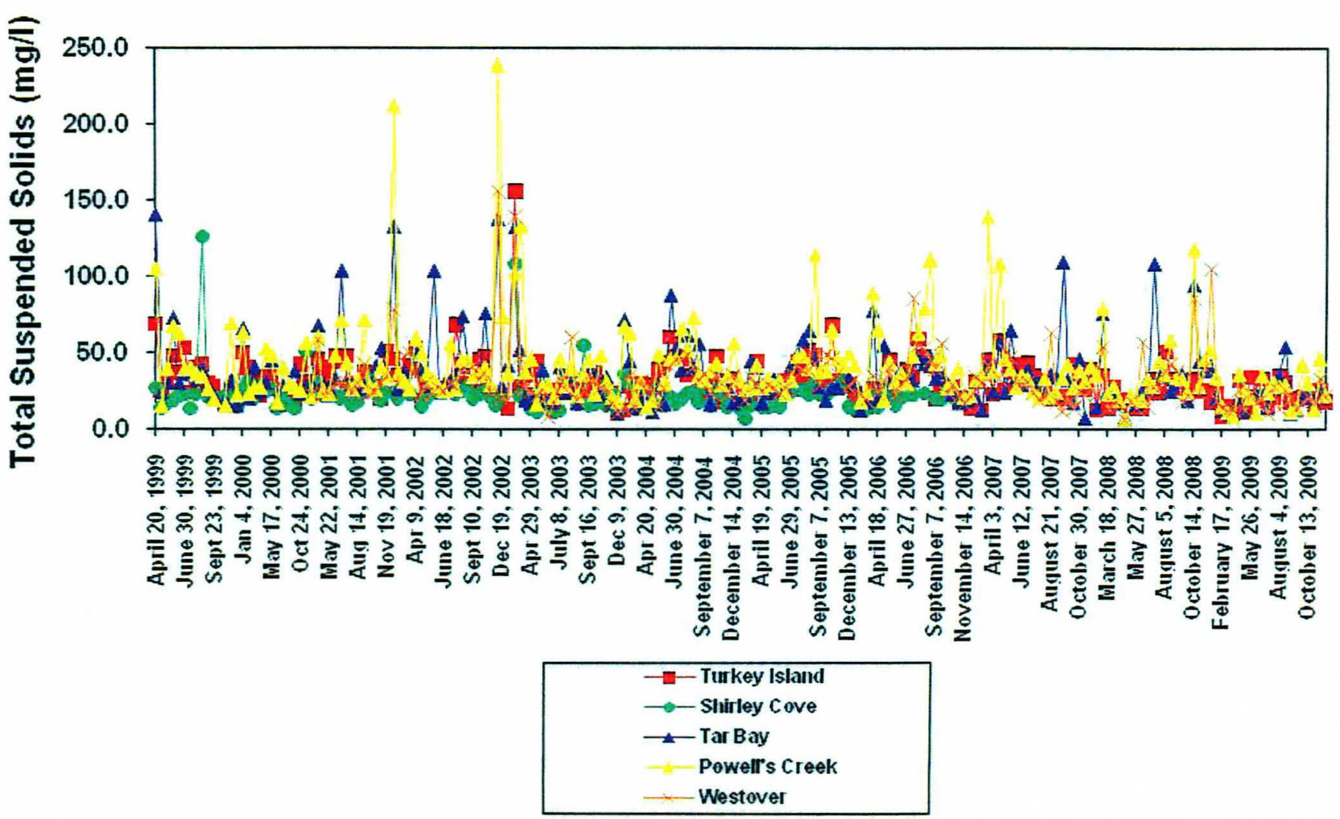


Figure 3-9. Secchi Depth

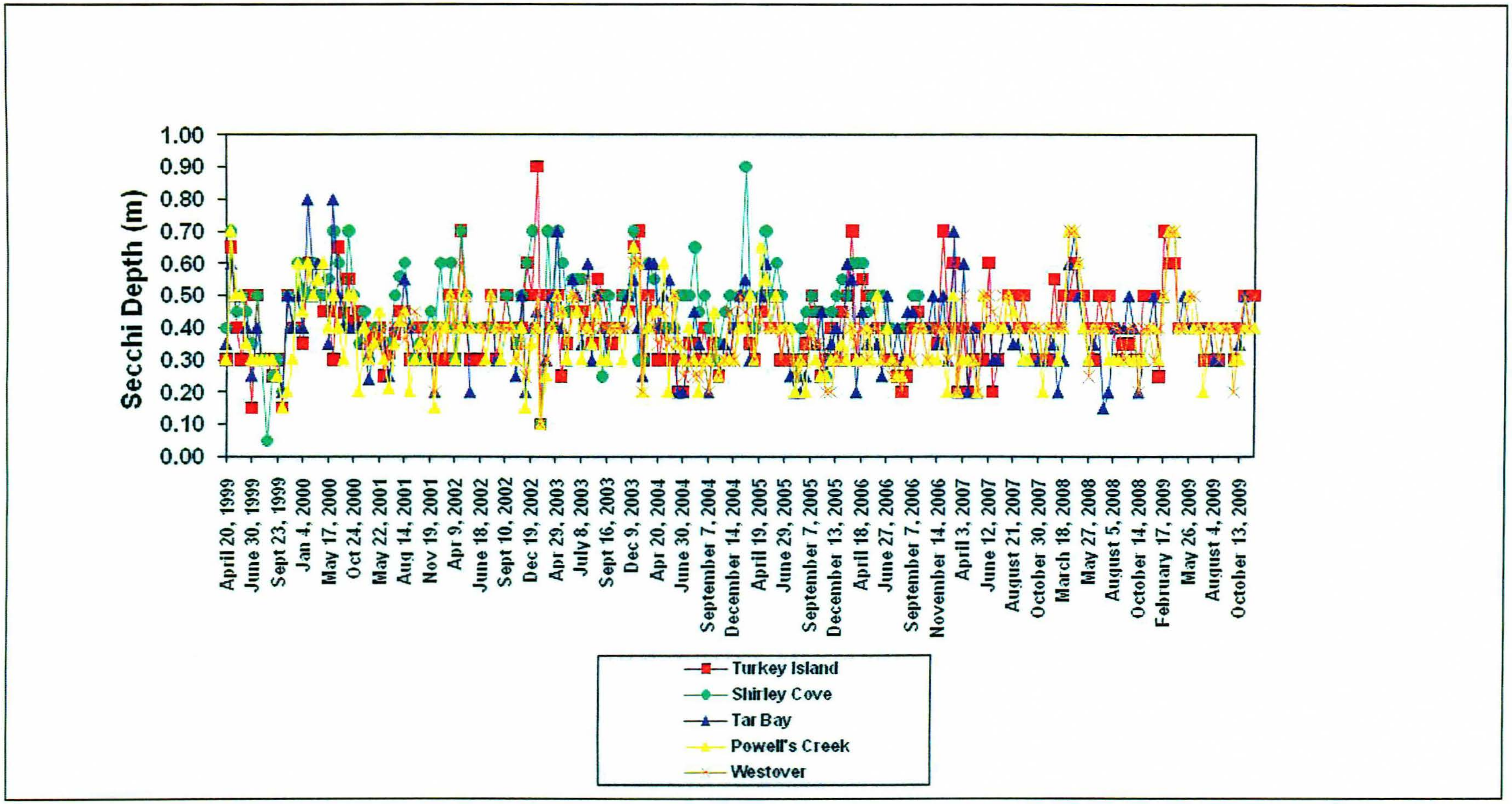


Figure 3-10. Light Attenuation (K_d)

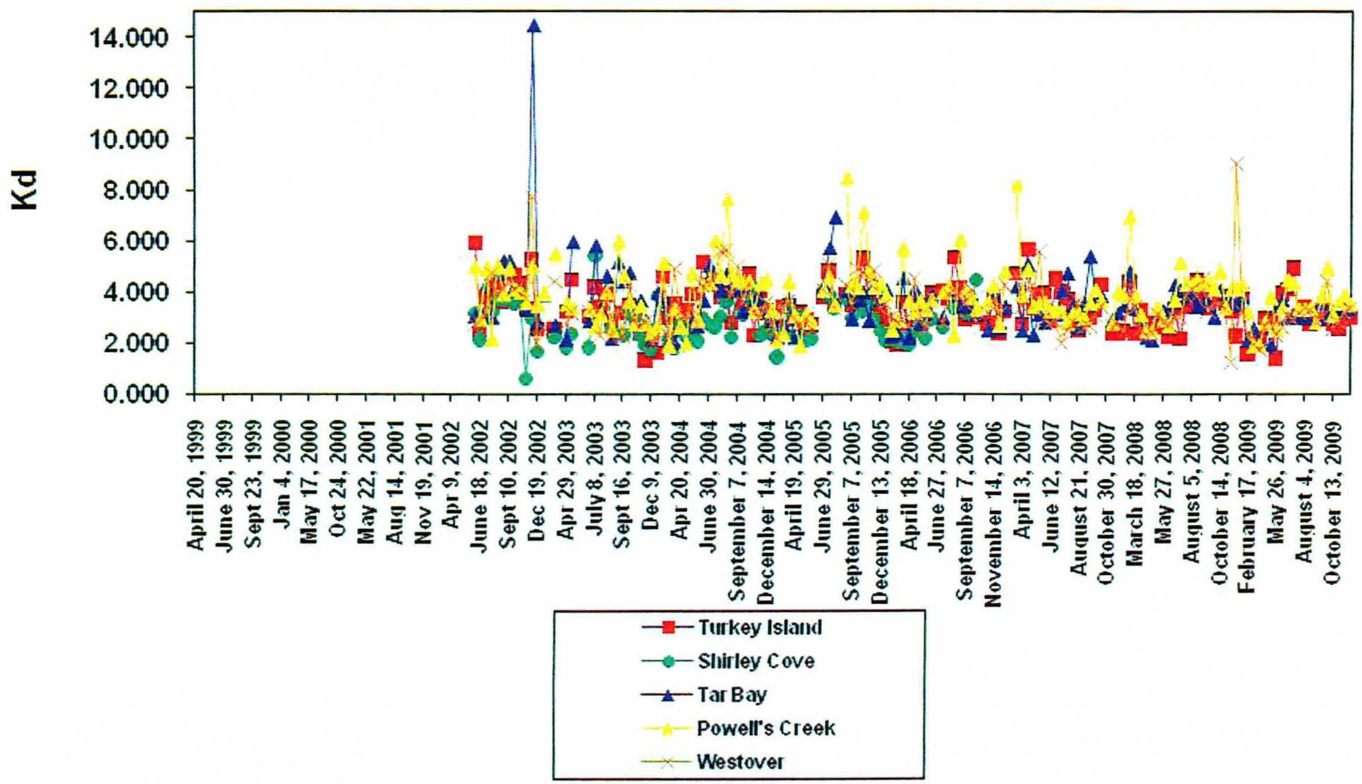


Figure 3-11. Chlorophyll a

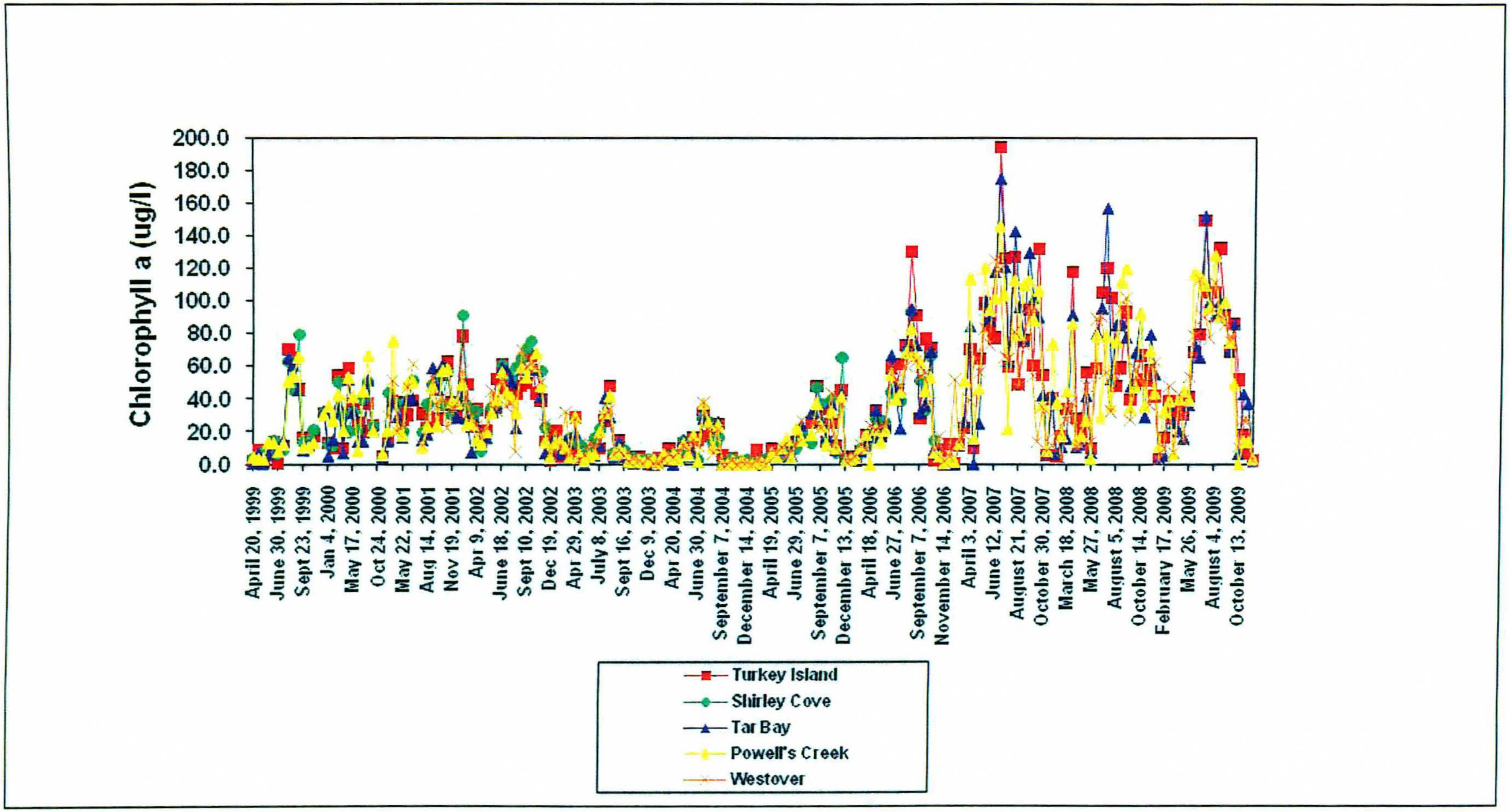


Figure 3-12. Total Organic Carbon (TOC)

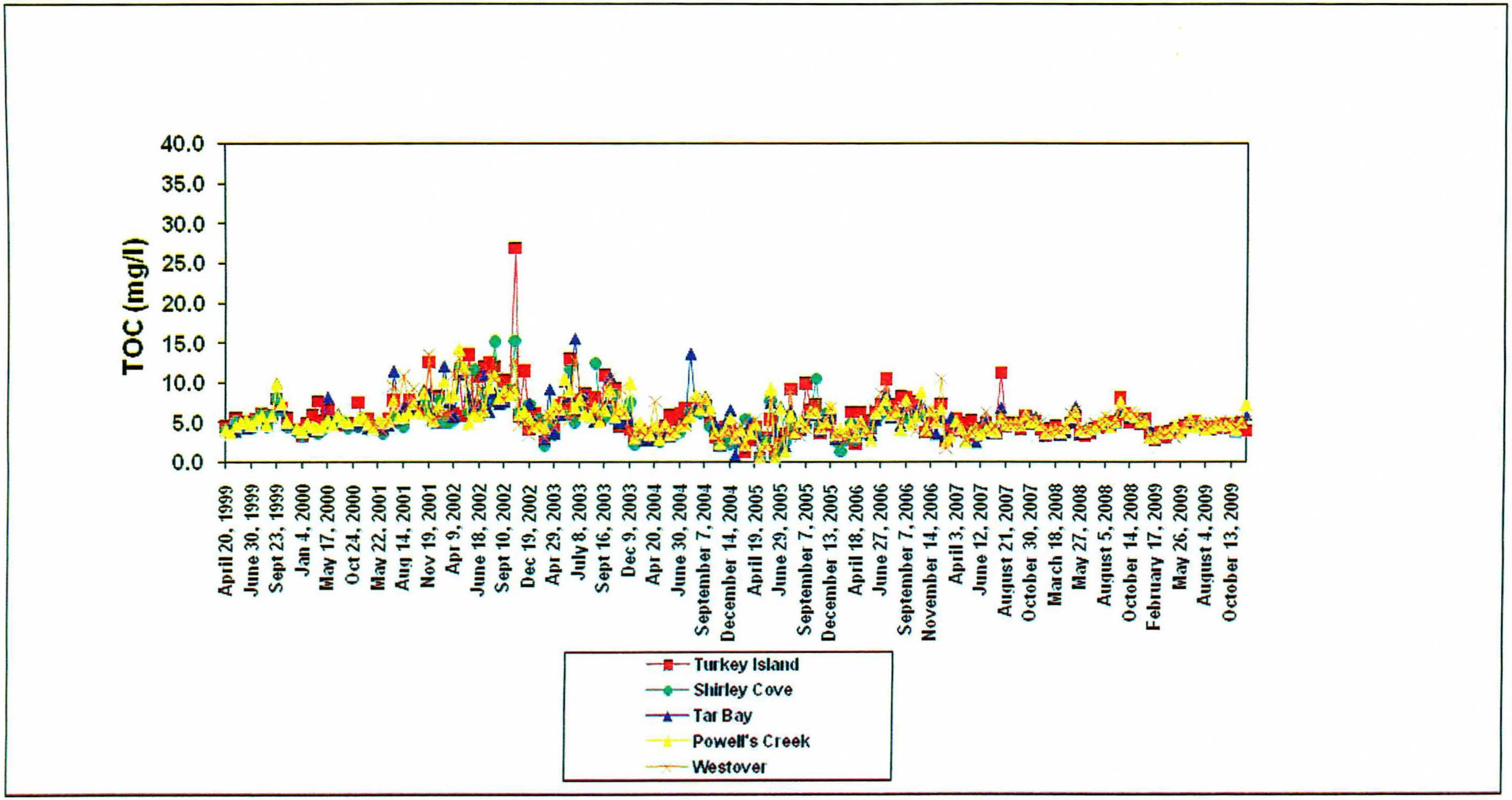


Figure 3-13. Total Kjeldahl Nitrogen (TKN)

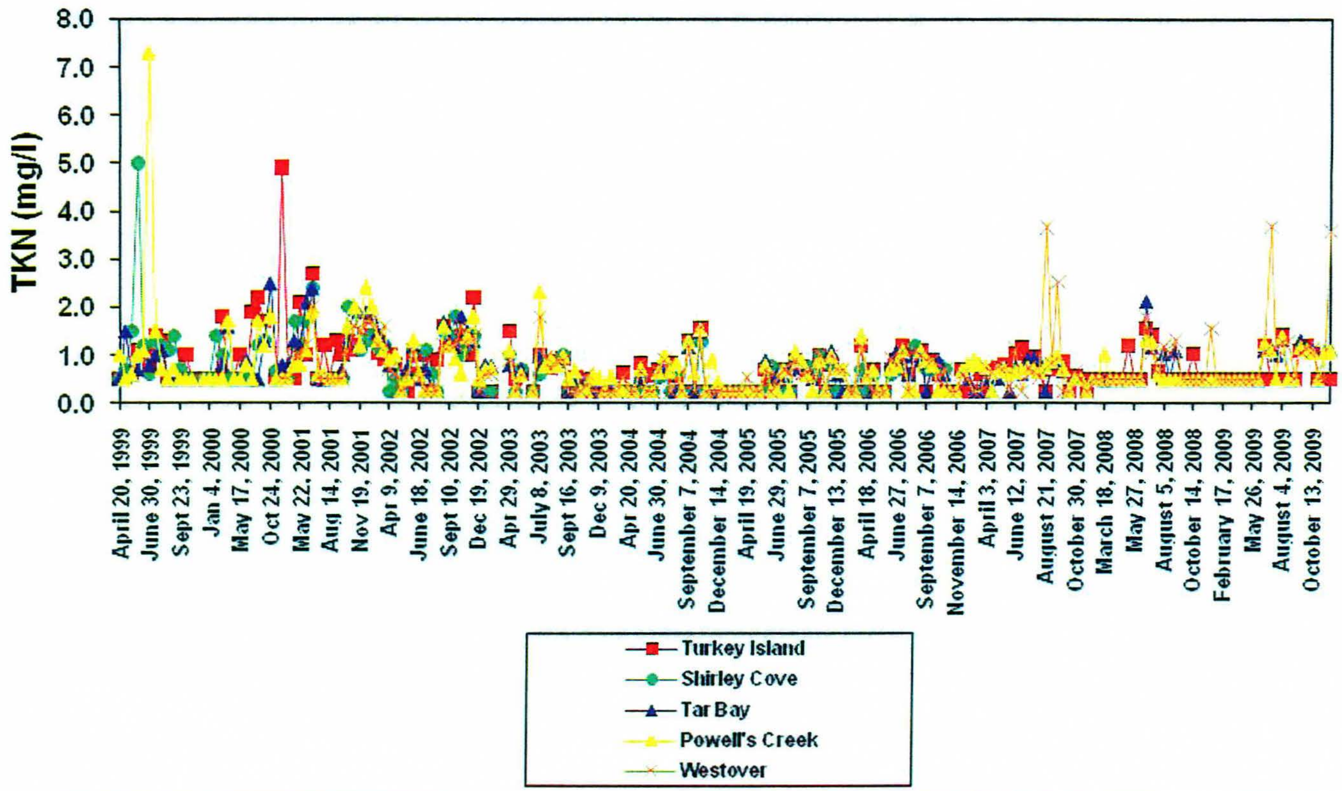


Figure 3-14. Total Phosphorus (TP)

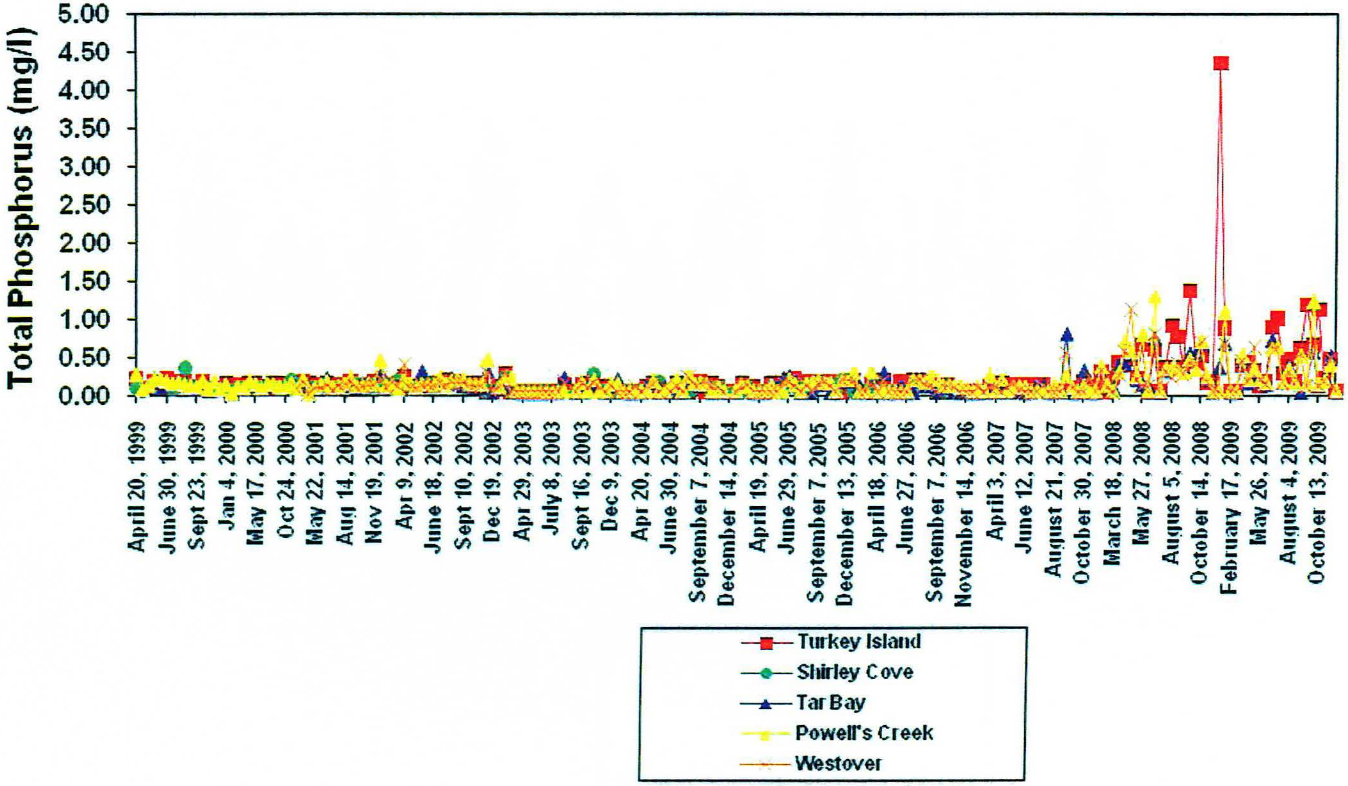


Figure 3-15. Dissolved Nitrate + Nitrite

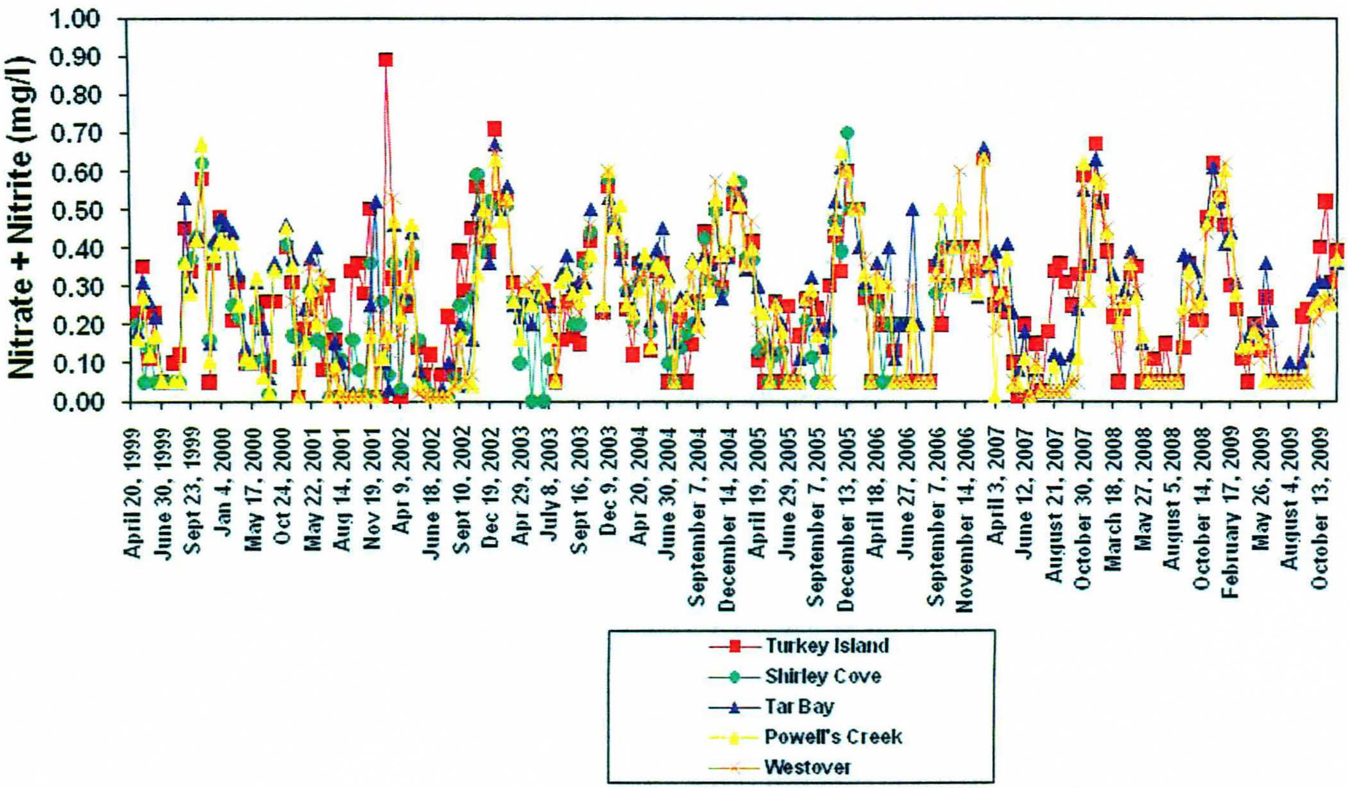


Figure 3-16. Dissolved Ammonium

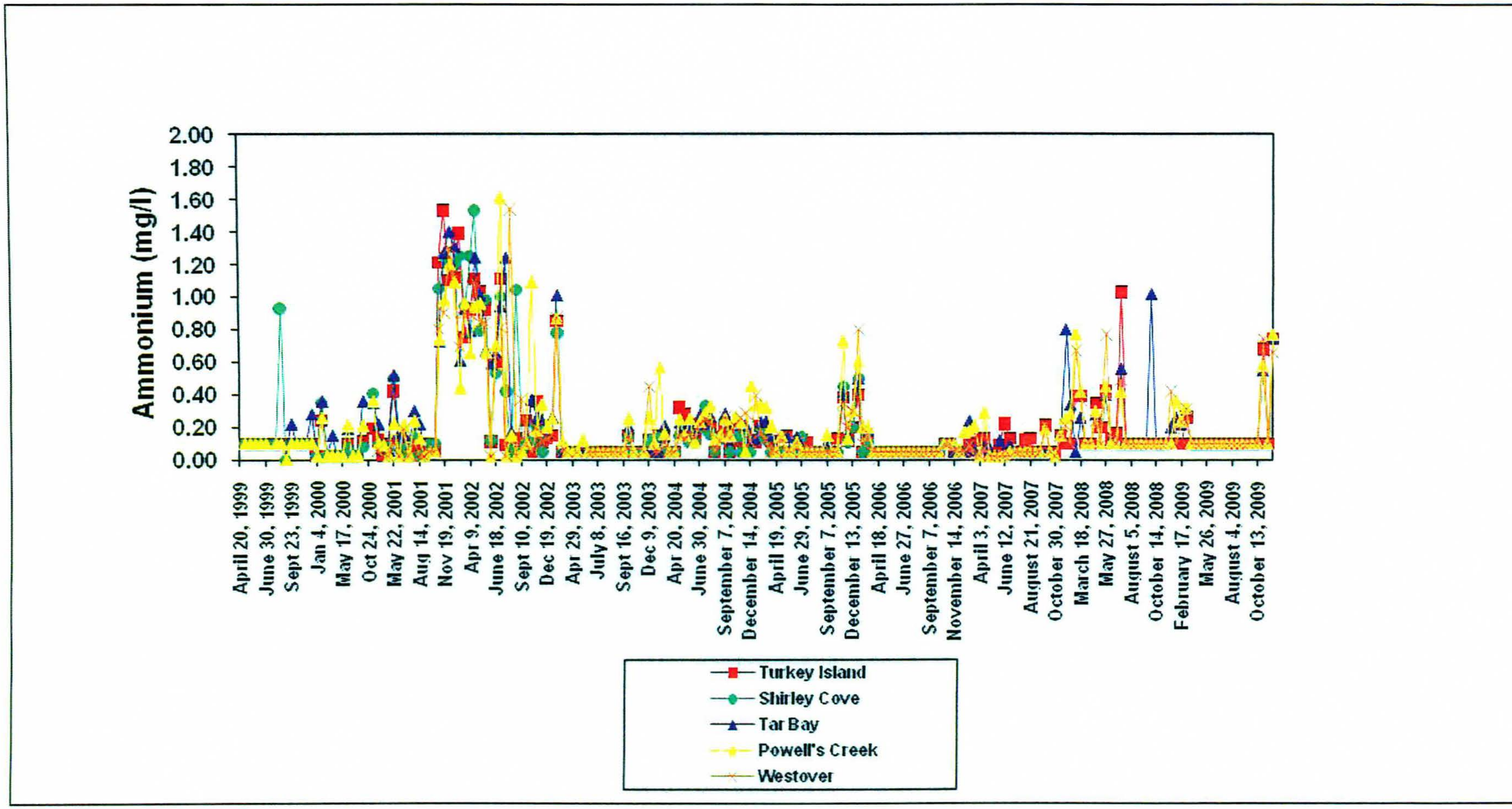


Figure 3-17. Dissolved Inorganic Phosphate (DIP)